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DEBRIS AND MICROMETEORITE IMPACT MEASUREMENTS IN THE LABORATORY

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INTRODUCTION

The damage potential to spacecraft by micrometeorites and orbital space debris has been recognized for some time. Damage caused by micrometeorites has been seen on the Solar Max Mission[1] and the LDEF Satellite[2] as well as other missions. Theoretical models (Kessler et al.[3]) suggest that most of the space debris in lower earth orbit (LEO) consists of particles smaller than 100 μm that travel at speeds of 10-15 km/sec (See Figure 1). Micrometeorites tend to move faster, at 20 km/sec, but are fewer in number compared to space debris.

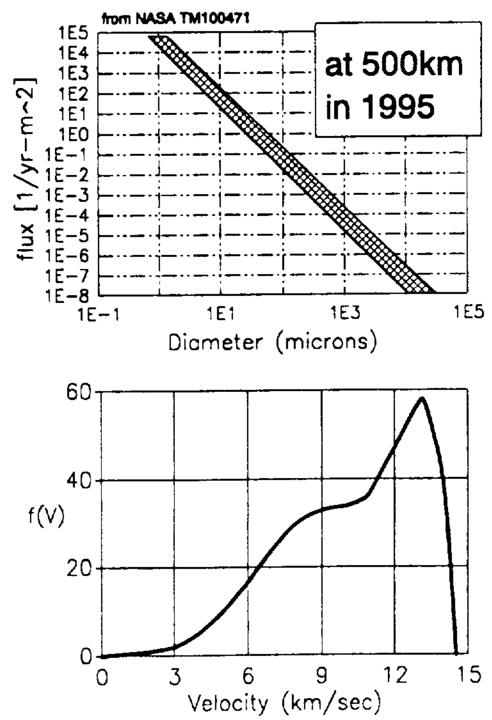


Figure 1: Size and Velocity of Micrometeorites in lower earth orbit

Since opportunities to retrieve and study space-exposed material are rare, we have developed a method to simulate space debris in the laboratory. This method, which is an outgrowth of research in inertial confinement fusion (ICF), uses laser ablation to accelerate material. Using this method we have accelerated single 60 μm aluminum spheres to 15 km/sec and larger 500 μm aluminum sphere to 2 km/sec. Also, many small (<10 μm diameter) irregularly shaped particles have been accelerated to speeds of 100 km/sec. Studies similar to ours have been reported by Borodziuk and Kostecki.[4]

LASER ABLATION

In the laser ablation method of accelerating particles, a powerful 5 ns duration laser pulse is focussed with an irradiance of 10^{13} W/cm^2 onto the surface of a projectile. This irradiation heats the surface of the particle to temperatures of a few hundred eV, causing the surface to evaporate very rapidly. This rapid evaporation of the surface is called laser ablation. Generally, a few microns of surface material are ablated and the speed of the ablated material is 100 - 800 km/sec. This ablated material, which behaves like the exhaust of a rocket, accelerates the projectile (see Figure 2). Using energy and momentum conservation equations, the velocity of the projectile and the pressures on the surface can be calculated[5]. For small amounts of ablated mass (ΔM), the velocity of the projectile (v), the ablation velocity (u), and the mass of the projectile M_0 are related by

$$v/u = \Delta M/M_0 \qquad (1)$$

Thus, for an ablation velocity of 700 km/sec where only 2% of the mass is ablated, a particle velocity of 15 km/sec is achieved. The pressure on the surface of the accelerated particle using this technique is enormous.

Extensive theoretical and experimental studies of this process have been done for many years in the ICF community.[6,7] A theoretical study of the use of laser ablation for accelerated small (100 μm and smaller) spheres has been performed by Goela and Green.[8]

THE EXPERIMENT

The experimental set-up is shown in Figure 3. The Nd-glass (1.054 μm wavelength) Pharos III laser was focussed onto the surface of the projectile mounted on a holder (see Figure 4). Laser energies of 50 to 300 J were used with a pulsewidth of 5 ns. The projectile, accelerated by the ablation from its read surface, collided with a flat target (usually glass) up to 3 cm away from the holder. The projectiles were 60 to 500 μm diameter aluminum spheres. Shots could be repeated up to once per hour.

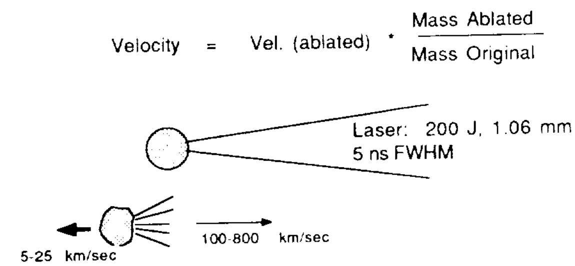
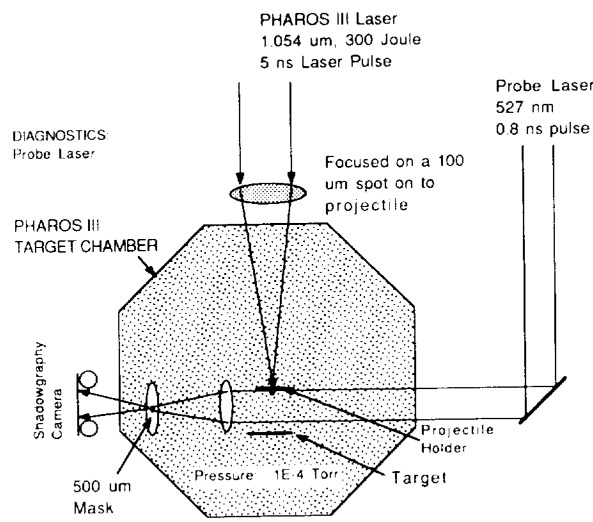


FIGURE 2: ACCELERATION BY LASER ABLATION



NOT TO SCALE

FIGURE 3
MICRO-METEORITE EXPERIMENT

To measure projectile velocities, dual-time dark-field shadowgraphy was employed.[9] This gave an image of the density gradients in the region surrounding the projectile and an image of the absorption region. In our experiment a sub-nanosecond pulsed 527 nm probe laser was directed across the path of the projectile. With two snap-shots (180 ns apart) of the projectile and debris as they moved away from the projectile holder, a velocity was calculated (see Fig. 5). Unfortunately, the electron density near the projectile due to the surrounding plasma is too high (above 10^{20} cm^{-3}) to see the outline of the projectile clearly. However, the plasma surrounding the projectile had little

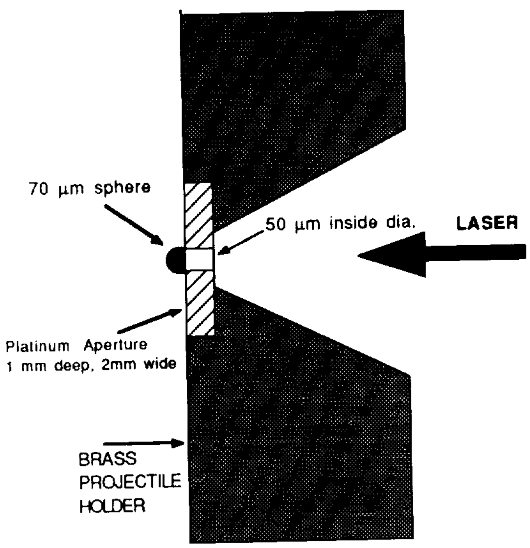
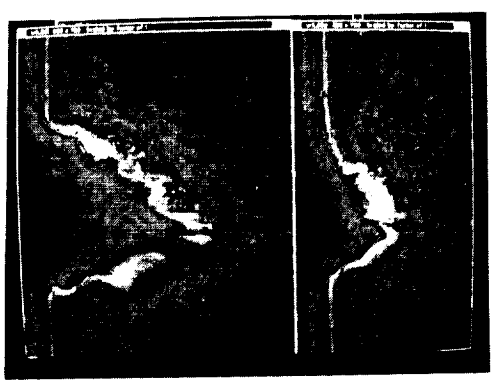


Figure 4

Projectile holder



t + 180 ns **t**

FIGURE 5

Velocity measurement through dark-field shadowgraphy

mass and therefore, little if any effect on the target being impacted (this can be seen from the crater size and the lack of contamination). We assumed that the speed of the projectile within the plasma and the leading edge of the plasma seen is the same. This is supported by the fact that our calculation of projectile velocity and the measured velocities agree. We believe the margin of error for this measurement is approximately +/- 10%. A better velocity measurement will be made in the future using x-ray probe that can pass through the plasma surrounding the projectile but is stopped by the projectile.[10]

RESULTS

Half-millimeter diameter aluminum spheres were accelerated to 2 km/sec and produced single craters on a glass slide having a layer of copper foil on the front. The copper foil was needed to prevent the glass from shattering and make it easier to view any contamination by the aluminum sphere or the surrounding plasma. The craters produced had diameters of 1.5 mm and little contamination by aluminum outside the crater was seen.

The crater diameter was 1.5 times the crater depth. Figure 7 shows a crater made by a 250 μm aluminum sphere on a similar target. In one instance a 140 μm aluminum sphere was shot into a 1/8" (3 mm) thick piece of glass, breaking it in half. Aluminum spheres 70 μm in diameter were accelerated to speeds of 15 km/sec. Figure 8 shows the resulting 1 mm diameter crater.

Table I shows the size, mass, and speed achieved for the different sized aluminum spheres used. To achieve the maximum speeds listed in Table I laser energies of 300 J were needed. Laser energies greater than 300 J did not increase the projectile velocities. At projectile speeds greater than 8 km/sec some melted aluminum was observed within the crater. At lower speeds very little material was seen within the crater Plastic projectiles of similar sizes were also used and found to have similar speeds as the same sized aluminum projectiles.

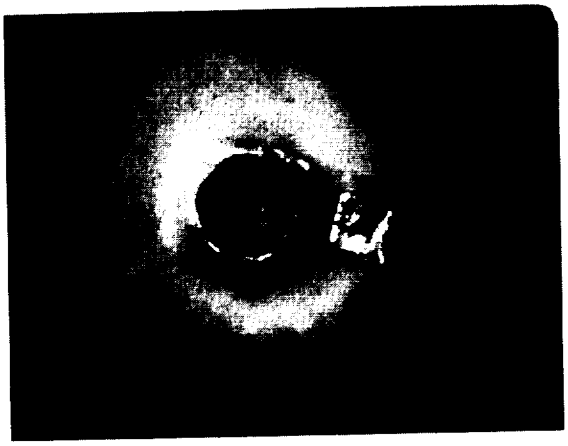


Figure 6: Crater in copper thin on glass from a 500 μm Al sphere at 1 km/sec.

<------------------------>
5 mm

Figure 8: 1 mm diameter crater on glass from a 70 μm Al sphere at 15 km/sec.

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1.25 mm

Figure 7: Crater on glass from a 250 μm Al sphere at 7 km/sec.

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5 mm

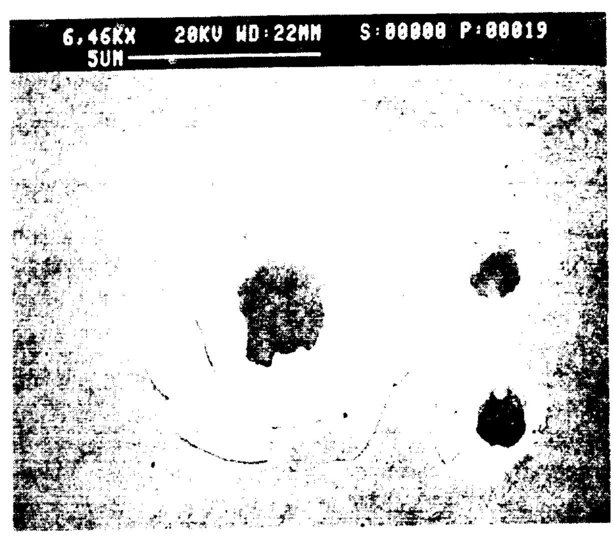

Figure 9: Examples of craters from irregular particles smaller than 10 μm traveling at speeds greater than 20 km/sec

TABLE I PROJECTILE PARAMETERS--
Aluminum

Projectile Diameter (μm)	Mass (μg)	Velocity Achieved
70	0.5	15 km/sec
140	4	12 km/sec
250	22	8 km/sec
500	177	2 km/sec

Thin foils 10 μm thick and 1 mm wide were accelerated using laser ablation. These foils broke up very quickly into many irregularly shaped particles smaller than 10 μm. These fragments impacted the targets at speeds of 20 to 100 km/sec. The greater speeds were possible due to the small areal mass of the material being accelerated. Figure 9 shows some of the craters formed on aluminum by such particles.

CONCLUSIONS

Acceleration of 70 μm aluminum and plastic spheres to speeds of 12 to 15 km/sec has been accomplished. Smaller irregularly shaped particles have been accelerated to speeds well above 20 km/sec. Given the ability to vary such parameters as projectile velocity, size, and incident angle, as well as the target and projectile materials, this technique should prove very useful for future studies of micrometeorite damage as well as hypervelocity impact (HVI) studies.

ACKNOWLEDGEMENTS

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